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A priority-setting scheme for the management of invasive non-native species in protected areas

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Abstract

Invasion by non-native species is one of the major threats to the conservation of biodiversity and to the provision of ecosystem services by protected areas. Invasive species often co-occur in protected areas, represented by sparse, isolated individuals or populations in different stages in the process of invasion. Species invasiveness, habitat invasibility and impact also differ between ecosystems, so the risk of invasion varies. Besides, prioritization is required due to constraints on time, financial and other resources. Priority-setting is therefore key to help protected area managers invest efforts on biological invasions that offer the best chances of producing large-scale positive results at the lowest cost possible. A priority-setting scheme for the control of invasive non-native species in natural areas is presented in this paper. The scheme, based on field observations of species occurrences, was applied to the Itatiaia National Park (Brazil). Priorities are calculated from a combination of three criteria attributed to each occurrence: species risk of invasion considering local ecosystems, invasion stage, and species frequency. Data collected in the field in the Itatiaia National Park were used to calculate priorities for 50 non-native species (six animals and 44 plants) in four locations in the Park. The highest priorities were attributed to species of high risk in an early stage

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of invasion occurring in one site, whereas a few widespread species of low risk were given lower priority. The scheme has proven functional for setting priorities for the control of non-native species in the Itatiaia National Park and in many other protected areas in Brazil.

Keywords

Invasion risk, invasive alien species, invasive species control, invasive species management, Itatiaia National Park, prioritization framework, priority-setting scheme, protected areas

Introduction

Invasion by non-native species is one of the major threats to the conservation of biodiversity and to the provision of ecosystem services by protected areas (Foxcroft et al. 2013; Hulme 2018; IPBES 2019). Although the quantification of impacts of invasive species focused on protected areas is still poor in most places (Hulme et al. 2014; Hulme 2018), studies have reported impacts ranging from predation and displacement of native species to changes in community structure and composition, as well as on disturbance regimes and ecosystem functioning (Turner et al. 1997; Loope et al. 2013; Ballari et al. 2015; Lessa et al. 2016; Schmidt et al. 2020).

The importance of protected areas in providing refugia for native species might be even more prominent under climate change (Gallardo et al. 2017). Thus, the control and eradication of invasive species in protected areas must be incorporated as a fundamental component of protected area management. In fact, international agreements and national regulations acknowledge the importance of this issue in different countries. For instance, targets are established in international agreements such as the Convention on Biological Diversity. National regulations, such as the Law 9985/2000 in Brazil, prohibit the introduction of non-native species in certain protected areas and define protected areas as priorities for invasive species control (Dechoum et al. 2018).

Invasive species often co-occur in protected areas, represented by sparse, isolated individuals or populations in different stages in the process of invasion (McGeoch and Latombe 2016). Species invasiveness, habitat invasibility and impact also differ between ecosystems, so the risk of invasion varies. At the same time, the opportunities to effectively eradicate or control invasive species are limited due to constraints on time, financial and other resources, lost opportunity costs and conflicting priorities (Robertson et al. 2003; Cheney et al. 2018). Therefore, priority-setting is key to help natural area managers invest efforts on biological invasions that offer the best chances of producing large scale positive results at the lowest cost possible (Gallardo and Aldridge 2013). A prioritization scheme is any structured system that produces a ranking or ordered set of risk categories (McGeoch et al. 2016). An effective priority-setting system should produce a list of priorities that enables managers to cover more area in less time to manage the best eradication or effective control opportunities first. This has been shown to be more efficient as a management strategy because small

invasions have a higher potential to spread than large invasions that have been established longer (Moody and Mack 1988; Emry et al. 2011). This approach is also preventative, especially when addressing populations that are somehow contained, and considers the relevance of early detection and rapid response strategies (National Research Council 2002; Reaser et al. 2020) to avoid future impacts. Individuals that are isolated, especially before reaching reproductive age, are therefore the highest priority especially in relation to those requiring long-term control (Moody and Mack 1988; Hoffmann et al. 2016). This approach also tends to translate into best cost-efficiency.

Priority-setting requires an appropriate evidence base for the definition of control and/or eradication targets (Gallardo and Aldridge 2013). In protected areas, a local assessment of invasive non-native species occurrences and invasion stage is essential for establishing management priorities, considering a preventative approach for the control of individuals or populations, and for actions aimed at eradication. Several prioritization methods have been used in other contexts to date. For example, Robertson et al. (2003) developed a scheme that used a multi-assessor approach for questions that resemble risk assessments. This scheme was used to define priorities based on species. Nel et al. (2004) derived lists of priority species for South Africa using available quantitative data on species distribution and expert knowledge. Later schemes, such as Forsyth et al. (2012) prioritized species first, then combined spatial data with stakeholder input to identify priority catchments for control in South Africa. Cheney et al. (2018) showed that systematic surveys are the best option to generate reliable data for priority-setting schemes, although the cost may be high. Available schemes such as these were however considered too complex for application by managers or field practitioners, too costly, or too time-consuming. In addition, while the majority of existing schemes focus solely on species, the scheme presented here focuses on species, populations and sites with the aim of identifying the best control opportunities of high-risk species, as in the reasoning of early detection and rapid response, and listing the remaining invasions in order of priority.

In this paper, we describe a priority-setting framework for the control of invasive non-native species in natural areas that essentially includes the knowledge of managers. This priority-setting scheme was initially developed in 2007 by the Horus Institute for Environmental Conservation and Development for application in protected areas in the state of Espírito Santo, in southeastern Brazil, and has never been published in the scientific literature. Priorities were defined for occurrences of invasive species in order to optimize control work and the use of financial resources. The scheme has since been used over the last 13 years to develop invasive plant species management plans for approximately 20 protected areas in Brazil. Managers receive training during the development of the plans and technical support to begin practical management. The resulting prioritization is adjusted for each protected area based on the knowledge of managers on local conditions, accessibility, costs, and the existence of susceptible or sensitive sites where control is urgent. A case study applied in the Itatiaia National Park (Brazil) using systematic sampling techniques for plants and mammals is included in this paper.

Methods

Priority-setting

The scheme used to define priorities for the non-native species observed in the Itatiaia National Park was applied to several protected areas over the years and a user-guide is available from the Horus Institute (Instituto Hórus 2008). The scheme is based on field observations of occurrences registered as individuals or populations of non-native invasive species in the area of interest. Priorities are calculated from a combination of three criteria attributed to each occurrence: species risk of invasion (R), invasion stage (S), and species frequency for each occurrence (F) (Fig. 1).

Risk of invasion by a species (R) is defined considering the non-native species' propensity to invade habitats in the area of interest, and can be (1) high, (2) moderate or (3) low. Species ranked as high risk are those with the largest potential to invade, and therefore the greatest potential for future impact. Evaluations of impact are not required for application of this scheme because this would create a level of complexity that would mostly hinder its practical use. The three levels of risk were defined as: (1) high – species recognized as invasive in many areas beyond the area of interest that tend to repeat the history of invasion locally due to environmental or climatic similarities; (2) moderate – species with a lower level of invasiveness which also tend to impact biodiversity at the local level and have a known history of invasion elsewhere, but less expressive than high-risk species, and; (3) low – species with scarce or no history of invasion that most often occur in degraded or agricultural areas and seldom become dominant. For our case study, the level of risk was defined by verifying whether the species was listed in the Database of Invasive Non-Native Species in Brazil managed by the Horus Institute (http://bd.institutohorus.org.br), which only includes non-native species that are invasive in natural ecosystems in Brazil. If the species was not listed, the Global Invasive Species Database (www.issg.org/database) and the CABI Invasive Species Compendium (www.cabi.org/isc) were consulted. The history of invasion across the world and records of impacts on natural areas were used to define the level of risk in the case study. Complementarily, the expert knowledge of the assessor, and especially of the protected area managers, was considered to ponder decisions on invasion risk.

The invasion stage (S) at each species occurrence is defined as: (0) contained, when individuals are under controlled conditions (e.g. greenhouse, pond or in cultivation), therefore not in direct contact with the natural environment; (1) casual, apparently not reproducing locally; (2) naturalized, when reproducing locally; or (3) invasive, involving reproduction and spread (sensu Blackburn et al. 2011).

Frequency (F) represents the spatial distribution of the species in each point of occurrence. It is registered as occurring in one single site (1), a few sites (2) or widely distributed in the sector or area considered (3). Distribution has to be considered in accordance with the scale of application. As this method can be applied at very different scales, attempts to define distribution in hectares or other units of measurement have not proven useful.

Combining the three criteria, the formula for calculating the level of priority is:

$$Pr = (R + S + F) - 2, \text{ where:}$$

Pr = level of priority,
R = species risk of invasion (1 = high, 2 = moderate, 3 = low),
S = invasion stage (0 = contained, 1 = casual, 2 = naturalized, 3 = invasive),
F = frequency (1 = one site, 2 = a few sites, 3 = widely distributed).

The highest priorities are attributed to species of high risk in early stages of invasion (contained or casual) that occur in one site (Fig. 1). The subtraction was included so that the highest priorities result as level 1. In the case of species contained in a laboratory, pond or in cultivation, the highest priority will result in zero (contained high-risk species in one site).

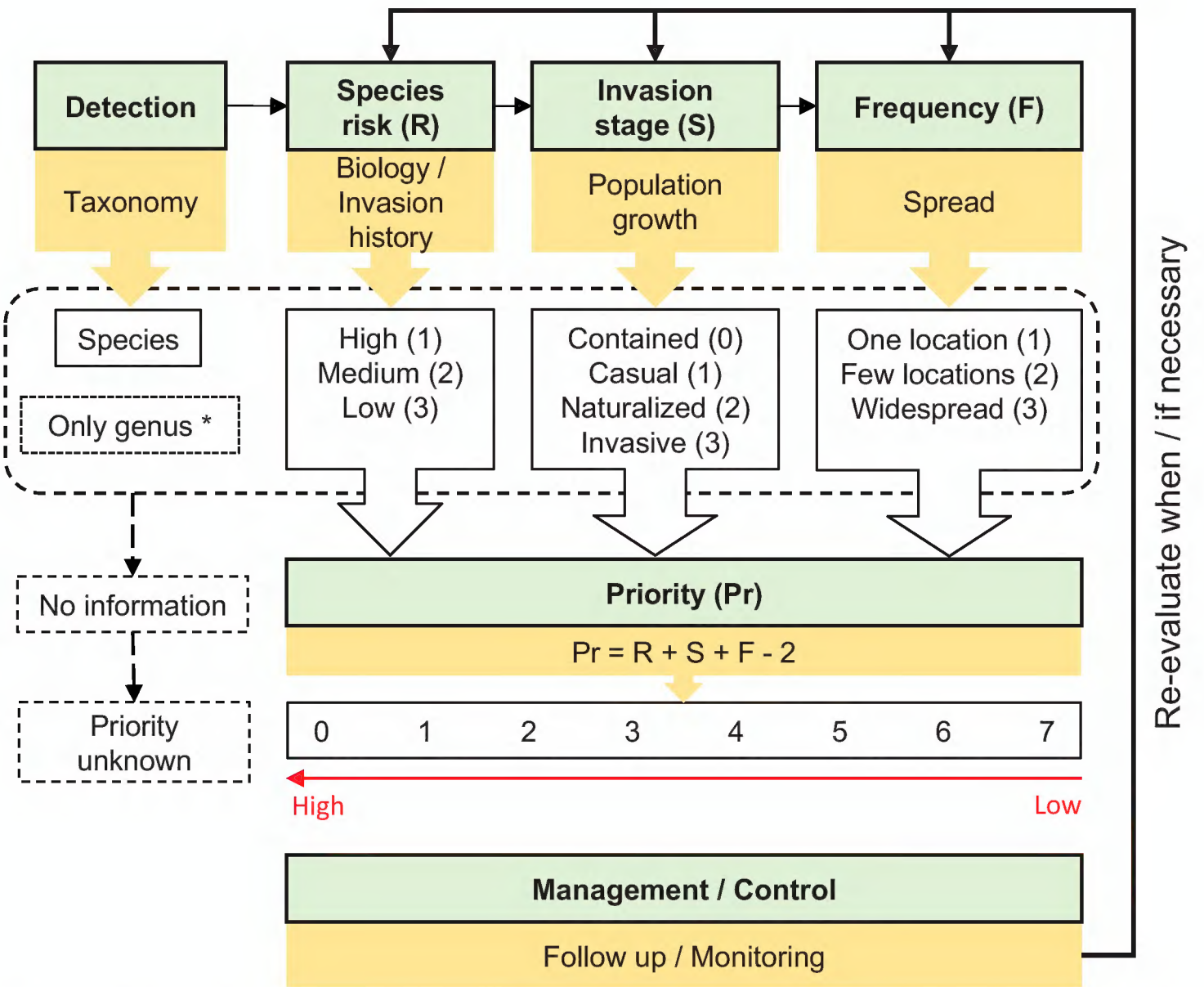

Figure 1. Conceptual framework of the priority-setting scheme for invasive non-native species control in protected areas. Priorities are determined for each species at each location in the protected area. (*) When an organism is not identified at the species-level, but the genus is known, the highest level of risk for a known species in the genus should be applied.

If the information for any of the criteria is not available, the priority cannot be calculated. This tends to happen if the species cannot be identified, as the level of risk would be difficult to estimate. Species from genera with several known invasive species, often difficult to distinguish at the species level, such as pines (*Pinus* spp.), eucalyptus (*Eucalyptus* spp. or *Corymbia* spp.), privet (*Ligustrum* spp.) or brachiaria (*Urochloa* spp.), none of which are native in Brazil, would have been included at the genus level. In this case, the precautionary principle is used to eliminate non-native species even if the precise identity is not known, and the highest level of risk for a known species in the genus should be applied.

Once species and populations have been scored, more nuanced factors (e.g. sensitivity of the area invaded, presence of threatened or endemic native species, invasiveness of the species in the protected area, and operational logistics) can be used to further refine priorities in close collaboration with local managers. Further details are provided in the discussion.

Study area

To test the prioritization scheme and determine its applicability to protected areas, the scheme was applied to the non-native flora and fauna of the Itatiaia National Park, Brazil (22°22'31"S, 44°39'44"W). The Itatiaia NP covers 28,084 ha and is located in the municipalities of Itamonte and Bocaina de Minas in Minas Gerais state, and Itatiaia and Resende in Rio de Janeiro state. The Park protects part of the Serra da Mantiqueira in the Atlantic Forest hotspot (Myers et al. 2000). According to the Köppen classification, there are two types of climate in the Itatiaia NP region: Cwb (temperate climate with dry winter and warm summer) and Cwa (temperate climate with dry winter and hot summer) (Arnfield 2019). The altitude ranges from 540 m to 2,791 m above sea level, with mean temperatures between 13 °C and 21 °C, and annual precipitation around 2500 mm (ICMBio 2014).

As in other protected areas classified as strict protection in Brazil, private properties whose landowners have not been compensated by the federal government remain within the Park limits. These properties include summer homes, hotels and hostels (mainly in the lowlands) as well as small rural properties (in the highlands) where the main economic activity is cattle farming (ICMBio 2014).

Data collection

The study area was subdivided in sectors identified by the Park staff: Serra Negra, Santa Clara, highland and lowland. Within each sector, sampling points where non-native species were present were considered an occurrence, while sampling efforts were conducted to determine invasion stage (S) and frequency (F) for each occurrence.

Mammals

To measure the presence and frequency of non-native mammals in the Park, camera traps were installed in 25 sampling points: four in Serra Negra, two in Santa Clara, nine in the highland and ten in the lowland (Fig. 2). Each sampling point was set at a minimum distance of 500 m from the next to ensure independence between samples. Three data collecting efforts of about three months each were conducted between September 2018 and July 2019. Cameras were installed by trails and inside forests. One camera-trap (Bushnell, Digital Hunting Camera, and Trail Camera) was placed in each sampling area, tied to a tree at approximately 30 cm above the ground. The cameras remained active day and night and were configured to take three pictures every 30 seconds once the sensor was triggered. In order to avoid data repetition, we computed the photographs discarding consecutive shots of the same individuals by the same camera at intervals shorter than one hour (Srbek-Araujo et al. 2012). The photographic records were analyzed to define the invasion stage for each mammal occurrence. Species were considered contained if on a leash or inside a cage or behind a fence in private properties (invasion stage = 0); casual, if only adults with no offspring were registered (1); naturalized, if offspring was present in only one photograph (2); and invasive, when offspring was registered in more than one photograph or by more than one camera (3).

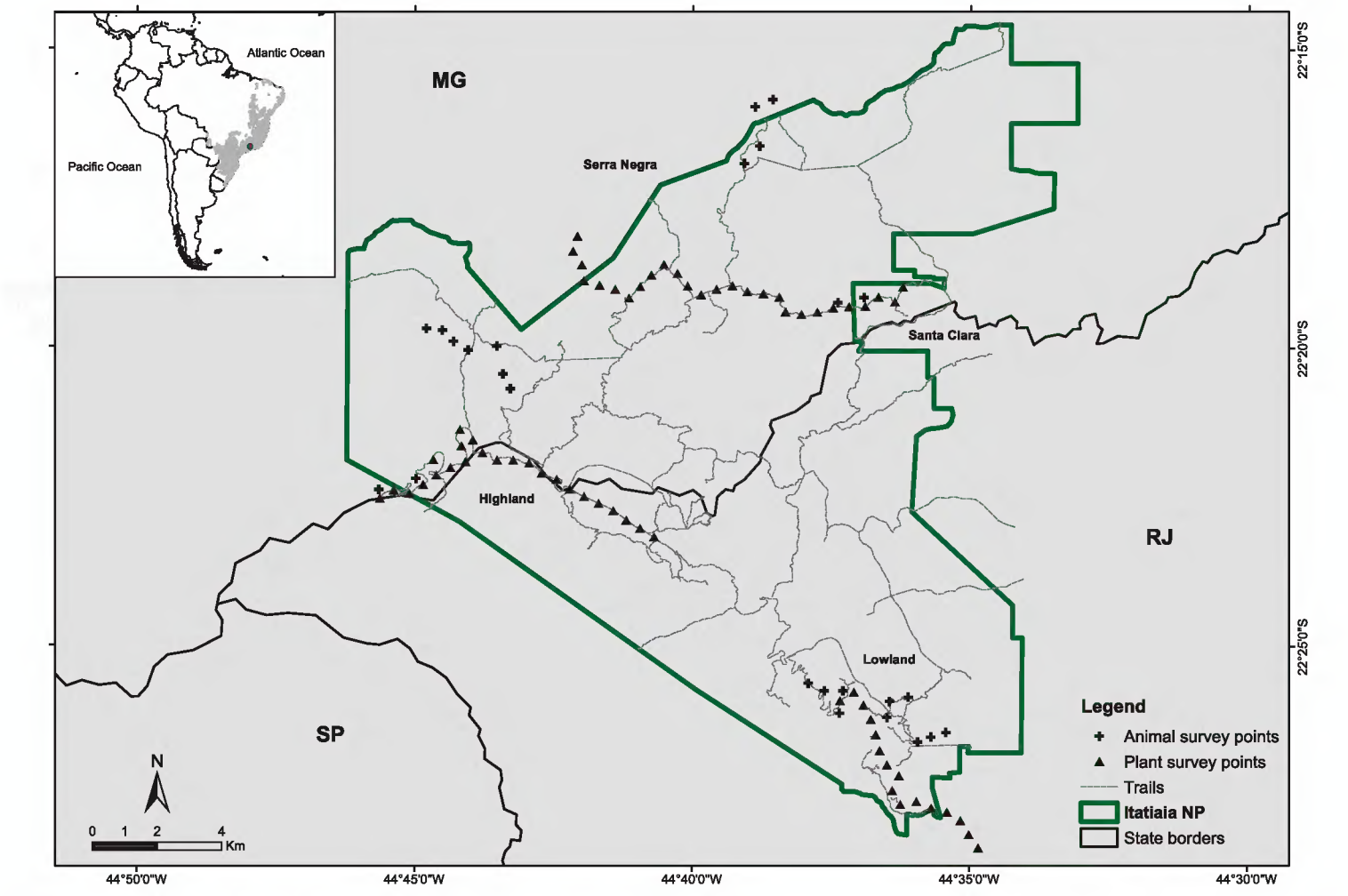

Figure 2. Map of the Itatiaia National Park with existing trails and sampling areas used for the survey of non-native mammals (crosses) and plants (triangles).

Plants

Non-native plants were surveyed in the four sectors of the Itatiaia NP along two roads and one trail, totaling *ca.* 25 km of linear area (Fig. 2). The road starting in the city of Itatiaia and continuing across the lowland for about 8.5 km to the Park headquarters was used to survey the lowland sector. The road accessible from Garganta do Registro continuing for about 25 km to the Rebouças shelter was used to survey the highland sector. The trail crosses two sectors of the park. Half of the trail is located on the northeastern face in the sector called Serra Negra. The other half of the trail is located on the northwestern face in the sector, Santa Clara. The ridgeline separates the two faces and, consequently, the two sectors.

Along the selected roads and trail, we marked sampling points every 500 m in a straight line. Each sampling point was comprised of three subplots for herbaceous plants and one transect for trees. The three subplots of 1 × 10 m each were installed parallel to the road or trail, the first by the edge of the road or trail, the second at a five-meter distance, and the third at a ten-meter distance. One 100 m transect parallel to the road or trail was set at each sampling point. We walked along the transect performing a visual search for non-native trees on only one side of the road or trail. If a non-native tree species was observed, we walked towards the plant to check for other plants of the same species or the presence of a population. If a population was present, offspring were counted and registered. In total, 24, 16, 14 and 13 sampling points were established in the highland, lowland, Serra Negra and Santa Clara, respectively. Additionally, other non-native species observed in the Itatiaia NP, but not registered in the plots or transects, were listed separately. Information on non-native species obtained from a literature review using the combination "alien" or "exotic" or "non-native" species and "Itatiaia National Park" on Google Scholar, from the Park management plan (ICMBio 2014), and from official newsletters available from the Park website (http://www.icmbio.gov.br/parnaitatiaia/) was also included.

The plant samples collected were identified at the Bioinvasion and Conservation Laboratory and at the ESAL Herbarium of the Federal University of Lavras. Species identifications were confirmed by the RB Herbarium of the Rio de Janeiro Botanical Garden. We also consulted the scientific literature to ensure that the species identified were not native in the Itatiaia NP. We classified species invasion stage in each sector using the definitions proposed by Richardson et al. (2000) and Blackburn et al. (2011). Plant populations of herbaceous species occurring in a few points on the edge of the road or trail or in cultivation, not spreading into native vegetation, were classified as casual (invasion stage =1); plant populations with self-sustaining populations of individuals occurring in the first and second subplots across several points were considered naturalized (2); and plant populations present in all three subplots in numerous sampling points were considered invasive (3). Trees occurring in a few points on the edge of the road or trail or in cultivation, not spreading into native vegetation, were classified as casual (invasion stage =1); plant populations with self-sustaining populations of individuals occurring only in the surroundings of adult plants with no detectable signs of spread were considered naturalized (2); and tree populations spreading farther than 100 m from adult plants in numerous sampling points were considered invasive (3).

Results

Four non-native mammal species were recorded in the Itatiaia NP after a total of 298 camera trap*day: domestic cattle (*Bos taurus*, n = 97), wild boar (*Sus scrofa*, n = 72), domestic dog (*Canis lupus familiaris*, n = 10), and European hare (*Lepus europaeus*, n = 1). Domestic cattle and wild boar were observed in six of the 15 sampling areas, domestic dogs in four, and European hare in one. Three species were observed in Serra Negra (*C. lupus familiaris*, *S. scrofa*, and *L. europaeus*) and three in the highland (*C. lupus familiaris*, *S. scrofa*, and *B. taurus*). No records of non-native mammals were obtained in Santa Clara or in the lowland. Invasion stage (S) was determined as casual for *B. taurus* and *C. lupus familiaris* in the highland, and for *C. lupus familiaris* and *L. europaeus* in Serra Negra. The invasion stage of *Sus scrofa* was determined as invasive in the highland and in Serra Negra. In terms of frequency, *L. europaeus* was observed in one point in Serra Negra, *C. lupus familiaris* in a few points in the highland and in Serra Negra, *S. scrofa* in many points in the highland and in Serra Negra, and *B. taurus* in many points in the highland. Based on the history of invasion of these species and considering the ecosystems in the Park, risk was rated low for *B. taurus*, moderate for *L. europaeus* and high for *C. lupus familiaris* and *S. scrofa*. Priorities were calculated based on risk, abundance, and spread, resulting in assignment of level 2 for *C. lupus familiaris* in both Serra Negra and the highland, level 2 for *L. europaeus* in Serra Negra and level 5 for *B. taurus* in the highland and *S. scrofa* in both Serra Negra and the highland (Table 1). The invasion risk factor can be considered as the most important factor to separate species/populations that have the same priority score. As such, because *B. taurus* does not have a significant history of invasion, the final adjustment on the scheme would place it as the last population to be managed unless other evidence indicated the need for urgent action.

A total of 36 non-native plant species were registered at the sampling points along roads and trails (Table 2). Of the 12 plant species in the highland, three species occurred only in casual populations, one in naturalized populations, and eight in invasive populations. In the lowland we registered 25 non-native species: 14 species in only casual populations, seven naturalized, and four invasive. In Santa Clara we registered

Table 1. List of non-native mammal species registered in the Itatiaia National Park, Brazil, and priority levels for management based on species invasion risk: 1 – high, 2 – moderate, 3 – low; Invasion stage: 1 – casual, 2 – naturalized, 3 – invasive; and frequency of occurrence: 1 – one location; 2 – few locations, 3 – widespread (Fig. 1). Priorities vary from 1 (highest priority) to 5 (lowest priority). The table is sorted by priority level, then invasion risk, then by family and Latin name except when species considered more relevant for control are shifted up within the same level of priority and risk based on expert knowledge.

Order	Family	Latin name	Area of occurrence	Invasion risk	Invasion stage	Frequency	Priority level
Carnivora	Canidae	*Canis lupus*	Highland	1	1	2	2
Carnivora	Canidae	*Canis lupus*	Serra Negra	1	1	2	2
Rodentia	Leporidae	*Lepus europaeus*	Serra Negra	2	1	1	2
Artiodactyla	Suidae	*Sus scrofa*	Highland	1	3	3	5
Artiodactyla	Suidae	*Sus scrofa*	Serra Negra	1	3	3	5
Artiodactyla	Bovidae	*Bos taurus*	Highland	3	1	3	5

Table 2. List of plant non-native species registered in the Itatiaia National Park, Brazil. Priority levels for management based on species invasion risk: 1 – high, 2 – moderate, 3 – low; Invasion stage: 1 – casual, 2 – naturalized, 3 – invasive; and frequency of occurrence: 1 – one location; 2 – few locations, 3 – widespread (Fig. 1). Priorities vary from 1 (highest priority) to 7 (lowest priority). The table is sorted by priority level, then invasion risk, then by family and Latin name except when species considered more relevant for control are shifted up within the same level of priority and risk based on expert knowledge.

Family	Latin name	Area of occurrence	Invasion risk	Invasion stage	Frequency	Priority level
Araceae	*Epipremnum aureum*	Santa Clara	1	1	1	1
Balsaminaceae	*Impatiens walleriana*	Lowland	1	1	1	1
Poaceae	*Megathyrsus maximus*	Lowland	1	1	1	1
Poaceae	*Cynodon dactylon*	Lowland	1	1	1	1
Cupressaceae	*Cupressus lusitanica*	Highland	1	2	1	2
Asparagaceae	*Dracaena fragans*	Lowland	2	1	1	2
Iridaceae	*Crocosmia crocosmiiflora*	Highland	2	1	1	2
Poaceae	*Eleusine indica*	Lowland	2	1	1	2
Poaceae	*Eragrostis plana*	Lowland	1	2	2	3
Musaceae	*Musa rosacea*	Lowland	2	2	1	3
Poaceae	*Poa annua*	Lowland	2	1	2	3
Rutaceae	*Citrus × limon*	Santa Clara	3	1	1	3
Asteraceae	*Bidens pilosa*	Santa Clara	3	1	1	3
Asteraceae	*Bidens pilosa*	Serra Negra	3	1	1	3
Asteraceae	*Cosmos sulphureus*	Lowland	3	1	1	3
Asteraceae	*Youngia japonica*	Lowland	3	1	1	3
Cupressaceae	*Cunninghamia lanceolata*	Highland	3	1	1	3
Fagaceae	*Quercus robur*	Highland	3	1	1	3
Hydrangeaceae	*Hydrangea macrophylla*	Lowland	3	1	1	3
Moraceae	*Ficus auriculata*	Lowland	3	1	1	3
Zingiberaceae	*Curcuma longa*	Lowland	3	1	1	3
Zingiberaceae	*Hedychium coronarium*	Lowland	1	3	2	4
Rosaceae	*Rubus rosifolius*	Santa Clara	2	2	2	4
Moraceae	*Morus nigra*	Lowland	2	2	2	4
Moraceae	*Musa rosacea*	Lowland	2	2	2	4
Commelinaceae	*Commelina diffusa*	Lowland	2	2	2	4
Commelinaceae	*Tradescantia zebrina*	Lowland	1	3	3	5
Saururaceae	*Houttuynia cordata*	Lowland	1	3	3	5
Poaceae	*Poa annua*	Highland	2	3	2	5
Fabaceae	*Desmodium adscendens*	Lowland	3	2	2	5
Poaceae	*Eragrostis cilianensis*	Santa Clara	3	2	2	5
Lauraceae	*Persea americana*	Lowland	3	2	2	5
Rosaceae	*Rubus rosifolius*	Highland	2	3	3	6
Asteraceae	*Galinsoga parviflora*	Highland	2	3	3	6
Polygonaceae	*Rumex acetosella*	Highland	2	3	3	6
Apiaceae	*Centella asiatica*	Serra Negra	3	3	2	6
Hydrangeaceae	*Hydrangea macrophylla*	Highland	3	3	2	6
Poaceae	*Eragrostis cilianensis*	Serra Negra	3	3	2	6
Poaceae	*Eriochloa villosa*	Santa Clara	3	3	2	6
Apiaceae	*Centella asiatica*	Lowland	3	3	3	7
Apiaceae	*Centella asiatica*	Santa Clara	3	3	3	7
Fabaceae	*Trifolium repens*	Highland	3	3	3	7
Lamiaceae	*Prunella vulgaris*	Highland	3	3	3	7
Poaceae	*Anthoxanthum odoratum*	Highland	3	3	3	7

seven non-native plant species: three species in casual populations, two naturalized, and two invasive. In Serra Negra we registered three non-native plant species: one species in casual populations and two in invasive populations (Table 2).

Invasion risk was considered low for 17 of the 36 species, while ten were rated moderately invasive and nine highly invasive (Table 2). None of the non-native plants registered in our survey occurred both in the highland and in Serra Negra, whereas only one species was recorded both in the highland and lowland, or in the highland and in Santa Clara. In total, four species were assigned priority level 1, three species level 2, fourteen species level 3, five species level 4, six species level 5, seven species level 6 and five species level 7 (Table 2). The lowland was the area with the highest number of species in priority level 1 (*C. dactylon*, *I. walleriana* and *M. maximus*), and the highland was the area with the highest number of low priority species (category 7: *A. odoratum*, *P. vulgaris* and *T. repens*). The four species in priority level 1 only occur in casual populations in one location, but are species of high invasion risk in the ecosystems considered. On the other hand, the five species categorized as level 7 are species with populations widespread due to cattle farming prior to the establishment of the Park, but these are ruderal species of low risk without significant history of invasion (Table 2).

Discussion

Details on the usability and application of a simple priority-setting scheme are described in this paper to support the management of invasive non-native species in protected areas. As per the prioritization scheme, the highest priorities for control were attributed to species of high invasion risk in early stages of invasion restricted to one location (e.g. *C. dactylon* and *C. familiaris* in this case study), whereas widespread species of low risk were given lower priority (e.g. *C. asiatica* and *B. taurus* in this case study).

Among the three criteria used in the priority-setting scheme, classifying species risk, interpreted as the propensity of a species to invade the local ecosystems, may be the most challenging part given the general lack of training of natural area managers and other field practitioners on invasive non-native species, or knowledge of species and their behavior in local conditions. In these cases, invasive species databases (e.g. the Horus Institute in Brazil, CABI ISC and ISSG GISD) as well as the EICAT scheme (Environmental Impact Classification for Alien Taxa) (Hawkins et al. 2015; Evans et al. 2016), or available results of risk assessments (e.g., online sources, da Rosa et al. 2018; Ziller et al. 2018) can be used in addition to field observations to support decisions on the level of risk of each species. The disadvantage of using generic information is that although there may be records of invasion, impact, or results of high risk from assessments that refer to other parts of the world, the information may not apply well to local ecosystems. Additionally, present and future climate and habitat types should be considered when using these alternatives whenever possible, and especially, expert opinion and field observations. Quantitative risk assessments are often underused because they tend to be time-demanding or require data that is not readily available (McGeoch et al. 2016).

Although the scheme proved useful to define priorities for control in the Itatiaia NP, knowledge of invasive species and their potential or current behavior in the ecosystems considered is important for its application. For instance, in our case study, the

inclusion of species such as *Hydrangea macrophylla*, *Bidens pilosa*, and *Quercus robur*, which are in turn cultivated (*H. macrophylla*) and ruderal, as well as species that require long-term, persistent control and have expanded beyond small and few patches, such as African grasses, pushed aggressive invasive species such as *Hedychium coronarium* and *Tradescantia zebrina* down the list because these have invaded larger areas in the Park. Species that are characterized as not invasive or ruderal, such as the ones mentioned above (*H. macrophylla*, *B. pilosa*, and *Q. robur*), should be placed in a separate table to ensure that all species with a history of invasion are treated first. An initial effort in separating species with and without invasive potential will help managers filter the most important populations and species for control. This information cannot be obtained from general data sources, as it refers to the local ecosystems under consideration, and requires expert opinion as well as field observations. For this reason, species referenced in global databases as ruderal or invasive only in agricultural areas should be considered of low risk unless invasive behavior is actually observed locally, or other evidence corroborates higher risk.

In this study, formal sampling techniques were applied for data collection on non-native species. Although systematic sampling will produce the best possible data set (Cheney et al. 2018), this is, however, not the only approach for data collection. With training and experience, protected area staff can conduct field surveys to register the occurrence of non-native species with a GPS, while noting down invasion stage and frequency, as well as inferring invasion risk. Furthermore, information can be obtained from published sources. Effective prioritization must consider not only invasive species and pathways, but also the sites most sensitive and susceptible to invasion (McGeoch et al. 2016). This information can only be obtained locally, therefore invasion patterns must be observed during the surveys and used in the attribution of invasion risk. Information from other references is useful to corroborate these assumptions, as mentioned before. Cheney et al. (2018) demonstrated how mistaken general perceptions can be, as there was substantive disagreement between datasets produced by managers and by systematic sampling, implying that field data has to be collected locally. The application of our scheme entails full cover of protected areas, or of entire sections in the case of former prioritization of sites for control, very large areas, or very limited financial resources. Input from protected area managers is key especially after an initial list of priorities is defined based on field surveys. Logistics, as well as potential impact on fragile areas or on areas with threatened or endemic species, are discussed to adjust the operational sequence. At this time, knowledge of the area, accessibility, transportation or walking time, and many other details are considered to adjust the sequence of priority areas and species populations. Still, it is the priority levels that guide implementation. This last phase in the application of the scheme allows for flexibility and incorporation of exceptional circumstances regarding threatened or endemic indigenous species, susceptible or sensitive sites that may justify shifting the order of some priorities.

It is always best to register species occurrences by sectors of a natural area that are well-known by those in charge of management (e.g. entrance, headquarters, bridge, specific trails and other names in use). Once the list of priorities is generated, local managers must decide which sectors should be treated first, for example, due to the presence of threatened native species, unique or fragile habitats combined with other complementary criteria

such as accessibility. Resulting workplans will only be useful if taking local experience and knowledge of protected area staff into account, especially to define implementation.

Control efforts should begin by addressing the priorities with the lowest numbers (priorities listed as 0 or 1 first, then 2, and so on up to priority 7). Priority zero indicates the occurrence of a non-native invasive species which might not yet have spread, providing an opportunity for elimination before it invades, but contained species may in certain cases not require management either because they cannot escape or because they are not aggressive. These occurrences should be evaluated on a case-by-case basis. Species of higher risk should be treated first within the same level of priority. The operational sequence of the priority-setting scheme should respect the list of priorities as much as possible, but is flexible to be adjusted to optimize logistics.

Because control requires persistence to prevent species from reproducing in order to reduce existing populations, monitoring and control are part of a continuous cycle once management begins (Fig. 1). This cycle ends either when the invasion is eliminated or due to other reasons such as limited funds or personnel, or others that lead to the interruption of activities. Complementarily, capacity-building for invasive species management is a key component of efficiency in the control of invasive species, especially to avoid wasting time and resources and to avoid missing important opportunities of restoring natural areas or creating negative references.

Most protected areas around the world face the threat of multiple invasive species and managers are required to implement control practices to limit the spread and impact of invasive species. However, resources and time are often limited for controlling all invasions at once (Robertson et al. 2003; Forsyth et al. 2012). Thus, priority-setting is key for the effective management of invasive non-native species (McGeoch et al. 2016). The priority-setting scheme presented in our paper is intended to be simple and functional for prioritizing invasive non-native species for eradication or control. As it has been designed for application by protected area managers or field practitioners, it can be readily implemented in any protected area.

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